

# **A NEW TEST METHOD FOR THE ASSESSMENT OF NECK INJURIES IN REAR-END COLLISIONS**

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## **ABSTRACT**

Whiplash injuries due to rear-end car collisions is one of the most aggravating traffic safety problems with serious implications for the European society. Yearly more than a million European citizens suffer neck injuries from rear-end car collisions, implying tremendous societal costs. Therefore the European Community has sponsored the European Whiplash project. The objective of this paper is to present a general overview of this project.

Accident studies show the relevance of rear impact related whiplash injuries and representative rear impact conditions in which whiplash is likely to occur. For the development of a Rear Impact Dummy (RID) typical human responses to rear impact are needed and were obtained with human volunteer and Post Mortem Human Subject tests at low speeds. Accident reconstructions were performed in order to derive injury thresholds for the dummy. Combining information from the accident investigations and the reconstructions, test methods for the evaluation of seats and head restraints were developed. Finally the dummy and the test methods were used to evaluate seats available on the European market.

## **INTRODUCTION**

Whiplash Associated Disorders (WAD) are one of the main causes of injury claims. A significant part of these whiplash injuries occur in rear-end impact, possibly combined with multiple collisions. Other causes of whiplash injuries are frontal and side impact and roll-over. Temming (1998) reports 46 % of all whiplash injuries found in the VW accident database to be due to single rear-end or multiple collisions. Hell (1998/2000) shows a number of 40% as a result of the German insurance database. Single collision rear impact causes 15 % of the total number of whiplash cases in another study of Temming (2000). Typical accident conditions were identified and used for the definition of representative crash pulses based on crash recorder data.

For rear-end collisions no test methods exist to study the protection offered to the car occupant, contrary to frontal and lateral collisions. It is expected that for rear-end accidents improvements

in vehicle design and in particular the seat/headrest system can lead to a significant reduction in the amount of whiplash injuries. Experimental methods for the evaluation of seat head restraint systems were developed based on typical rear-end accident conditions.

In order to assess the injury risk in rear-end impacts, an adequate tool for injury assessment is needed. Several attempts have been made to design a crash test dummy, which sufficiently describes the human body kinematics and loads. The generally used Hybrid III dummy has been evaluated by several researchers. Prasad et al. (1997) compared the Hybrid III response to two cadaver tests performed by Mertz and found the dummy response satisfactory compared to the PMHS response. Others conclude that the Hybrid III lacks biofidelity in rear impact (Scott (1993), Davidsson (1998a & 1999b) and Cappon (2000)). The study by Davidsson resulted in the development of the BioRID dummy (Davidsson, 1998a & 1999a), which has a multi-segment spine. Within the European Whiplash project a crash dummy, called RID2, was developed parallel to and independent of the Swedish development. The RID2- $\alpha$  prototype was designed and evaluated on the basis of tests with human subjects conducted in this project.

Thus accident studies and accident reconstructions resulted in the definition of test methods. Human responses were used for the development of a rear impact dummy. Finally the testing procedures and the dummy were used in experimental benchmark studies with existing seat designs.

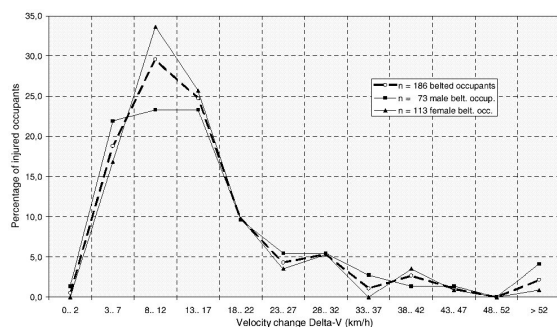
## **ACCIDENT STUDIES**

Knowledge on the protection of the human body in rear-end collisions is still very limited. Accident investigations were performed, in order to gain knowledge on injury causation and human body responses in rear-end collisions.

From the German insurance database 517 rear-end cases were investigated (Hell, 1998). In this study 673 occupants, of the 833 involved, claimed cervical spine injury (80%). This study showed that a typical rear-end accident configuration, in which whiplash injury occurs, is a 0-5° angled impact

with almost full overlap. The  $\Delta V$  of these cases was found to be in between 9 and 20 km/h. High head restraint positions were found to correlate with reduced injury risk and females showed a 1.4 times higher occurrence of injuries.

Another source of accident data was the Volkswagen Accident Database (Temming, 1998). In the 533 rear-end collisions, 297 of 1295 belted occupants sustained whiplash injuries (24%). The risk of female occupants suffering whiplash injuries, was found to be twice as high as the risk of male occupants. The  $\Delta V$  with the highest absolute number of injured occupants was in the range of 8-12 km/h. The maximum risk of injury was found in the  $\Delta V$  range of 13 to 17 km/h (velocity change at which the percentage of injured occupants is the highest, Figure 1. All injured occupants is 100%).



**Figure 1. Relation between the risk of whiplash injury and  $\Delta V$  (single rear-end impact, belted occupants).**

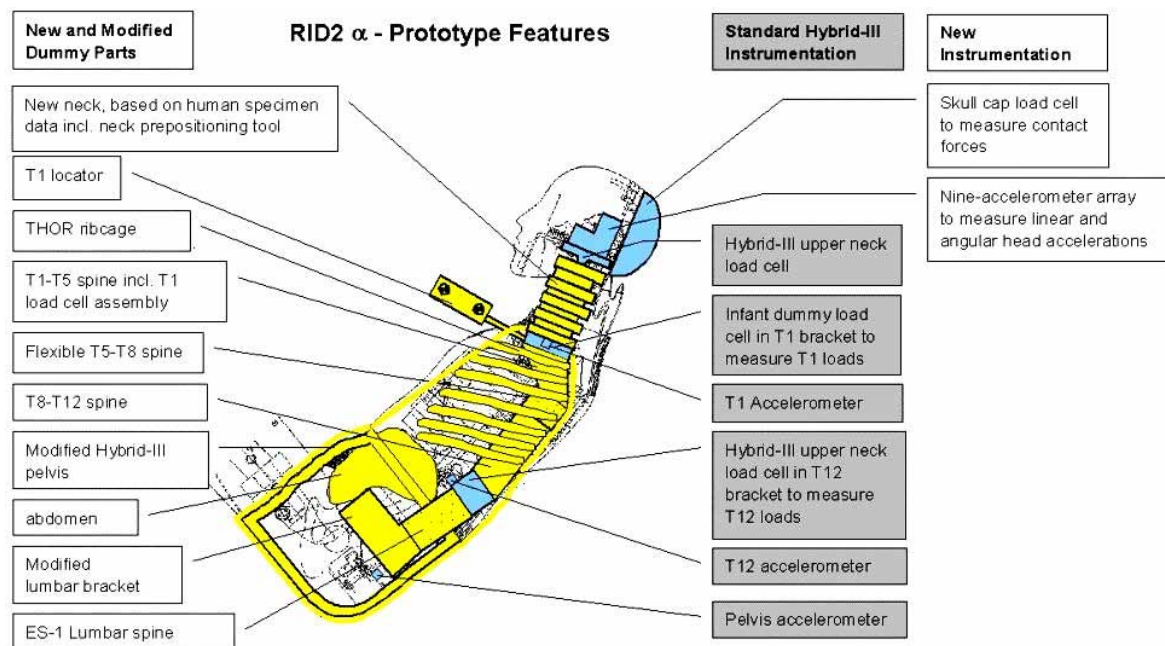
## HUMAN BODY RESPONSES

Biofidelity with respect to human subject impact response data is one of the most important design criteria for a crash dummy. At the start of the European whiplash project there were hardly any reliable human response data in rear-end impacts available. Therefore two series of sled tests were performed using human volunteers and Post Mortem Human Subjects (PMHS), respectively. A summary of the test conditions is presented in Table 1 and detailed results are presented by Kroonenberg (1998) and Bertholon (2000).

**Table 1. Characteristics of volunteer and PMHS sled tests**

	Volunteer	PMHS
Seat Type	Car seat	Rigid
Head restraint	Yes	No
No. of subjects	10	3
Max sled pulse [g]	4	12
Velocity [km/h]	6.5 and 9.5	10

From the knowledge and data obtained in these tests a crash dummy for low and mid-severity rear-end collisions was developed called RID2- $\alpha$  (Cappon, 2000). The following section will describe the RID2- $\alpha$  in general. Then a comparison of this dummy and the Hybrid III with the performance of the human subjects will be made.



**Figure 2. New and modified dummy parts and instrumentation.**

## RID2- $\alpha$ PROTOTYPE

As mentioned earlier several studies have shown the lack of biofidelity of the Hybrid III dummy in rear-end impact studies. In particular this dummy was found to lack head rotation during rear impact. This was mainly caused by the rather stiff neck of this dummy. Therefore the 2D TRID-neck was designed in 1996 (Thunnissen, 1996). This development was continued in the RID1 dummy, designed at the start Whiplash project, based on the limited amount of biomechanical data available at that time. Both the TRID-neck and the RID1 neck used the Hybrid III torso as a basis. From the evaluations done with the TRID-neck and the RID1 dummy it was found that there was no rotation at the base of the neck (T1 level) contrary to human responses and neither did the Hybrid III torso show any ramping up during rear impact due to inadequate interaction with the seat. Furthermore the TRID and RID1 neck were still too stiff. Therefore it was decided to develop a new dummy, which is the RID2.

The RID2- $\alpha$  prototype is a combination of newly developed parts and parts of the Hybrid III 50<sup>th</sup> percentile male dummy. Legs, arms, head are taken from the HIII dummy and mounted on the torso of the RID2- $\alpha$ . The torso has a new spine, which contains two flexible elements to allow spine rotation, and includes a THOR ribcage. The pelvis is equipped with a lumbar spine-bracket, which allows adjustment of the pelvis angle, to allow different seating postures.

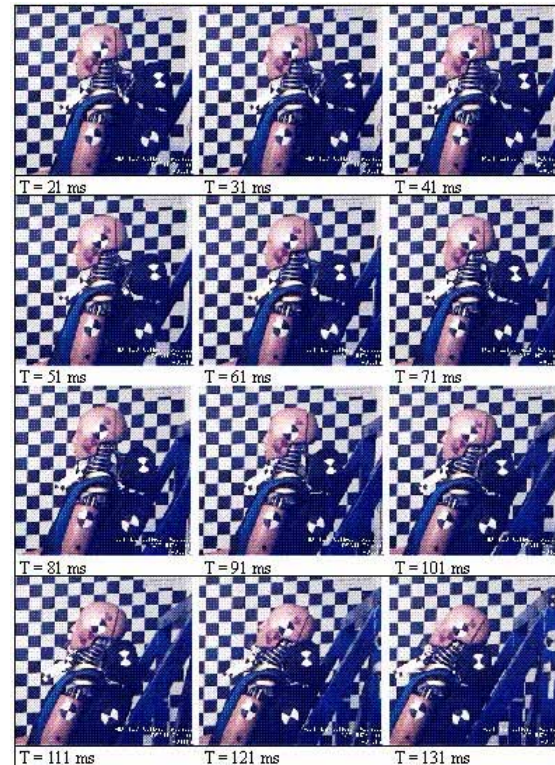
The neck of the RID2- $\alpha$  is a totally new development. It is optimised for low- and mid severity rear impacts. The major biofidelity design target was the initial translating motion of the head observed in human subject tests, resulting in an S-shape in the neck during rear impact (the so-called head lag).

The instrumentation of the dummy as well as the new and modified dummy parts is shown in Figure 2. In addition to the sensors shown, the dummy was instrumented with special tilt sensors, which allowed exact initial positioning before each test.

## RESULTS OF BIOFIDELITY TESTS

A detailed presentation of the dummy responses will be the subject of a separate paper. Figure 3 shows the global dummy response of the RID2- $\alpha$  in a low severity test (10 km/hr and 3.5 g). Clearly the initial translational motion of the head and the S-shape response of the neck can be observed. In the next section some global kinematics will be presented i.e. the T1 displacements and the head

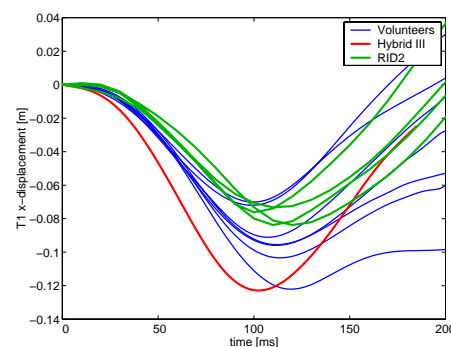
rotation in comparison with the human volunteer and PMHS tests. A comparison with the Hybrid III dummy will be shown as well.



**Figure 3. Sequence of the RID2- $\alpha$  head-neck response in 10 km/h, 3.5g impact.**

## Volunteer and soft seat configuration (AZT)

The T1 x-displacements as function of time with respect to the sled are shown in Figure 4. The translation of the RID2- $\alpha$  dummy is similar to the volunteer results, while the Hybrid III starts to move too early.

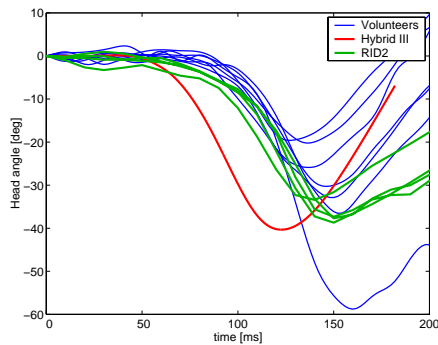


**Figure 4. T1 x-displacement**

The RID2- $\alpha$  head rotation as function of time with respect to the sled is similar to the volunteers' response for the RID2- $\alpha$  as is shown in figure 5. The timing of the dummy equals the timing of the volunteers. The Hybrid III shows almost no initial

head translation phase (S-shape) and starts rotating immediately. Due to the head restraint the rotation is limited in all cases.

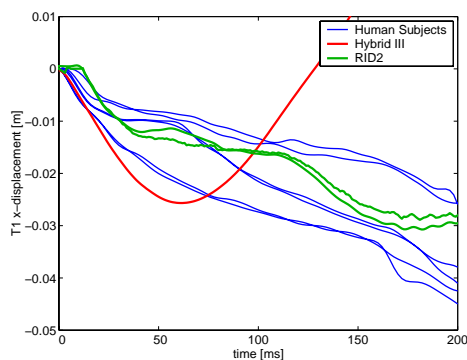
Compared to the human subject tests the RID2- $\alpha$  dummy did not show sufficient ramping-up yet and therefore some small modifications of the dummy design are needed. Another observation was that the RID2- $\alpha$ 's seating height was too large and a reduction in dummy length would be needed in order to obtain a more representative response. In the dummy version which will become available in spring 2001 these modifications will be included.



**Figure 5. Head angle with respect to the sled.**

#### Rigid seat configuration (LAB)

The T1 x-displacement is shown in Figure 6. It shows that the RID2- $\alpha$  dummy response is quite similar to the results of the PMHS tests, while the Hybrid III shows a very fast rebound. It must be noted that the Hybrid III T1-displacements were not derived from film analysis, but from acceleration measurements and thus contains more inaccuracies.

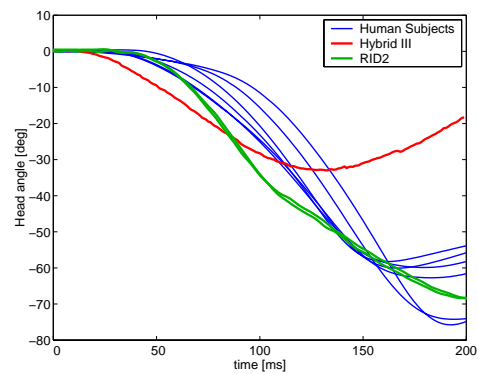


**Figure 6. T1 x-displacement with respect to the sled.**

The dummy's T1 z-displacement measured from the film is 25-31 mm upward (ramping-up). In the

PMHS tests, the displacement was highly dependent on the tested subject. The ramping effect, which is known to occur in human volunteer subjects and which will affect the relative position of the head with regard to the headrest at the moment of impact, is well reproduced by the dummy.

The rotation of the head with respect to the sled is illustrated in Figure 7. Much larger head rotations in these tests can be observed than in the human volunteer tests due to absence of a head restraint system. The peak rotation is very well reproduced by the RID2- $\alpha$  dummy in contrast to the Hybrid III dummy which shows about 50% smaller rotation. The initial head rotation in the RID2- $\alpha$  is slightly deviating from the PMHS response probably due to a different T1 rotation of the dummy.



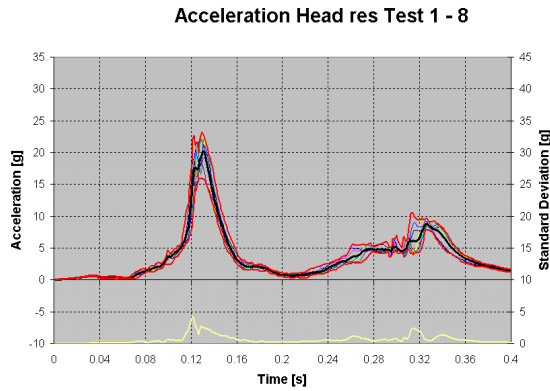
**Figure 7. Head angle with respect to the sled.**

#### Repeatability of the RID2- $\alpha$

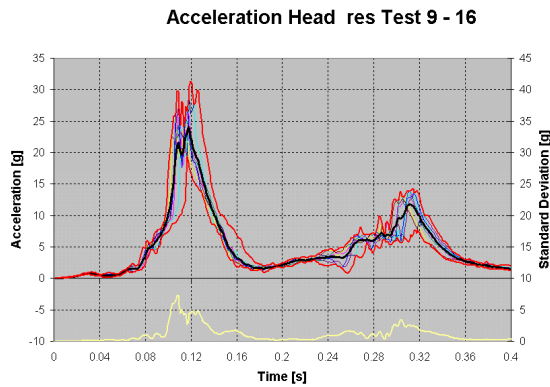
The repeatability of the dummy is tested using two different acceleration pulses, which are also proposed in the sled test method hereafter. Each pulse was used for a series of eight tests.

1. Test 1 to 8 were performed at an acceleration of 3.5g and a velocity change of 10km/h. This pulse is considered to designate the threshold below which injuries of human beings are improbable.
2. Test 9 to 16 were performed at an acceleration of 5.5g and a velocity change of 16km/h. This pulse simulates rear-end impacts at which neck injuries are very likely to occur.

Figures 8 and 9 show the head resultant acceleration of the RID2 illustrating the high repeatability of the dummy in both sled test scenarios. As there are only slight differences, one might conclude that this method is quite robust.



**Figure 8. Head resultant acceleration of RID2- $\alpha$  in 10 km/h, 3.5g sled test.**



**Figure 9. Head resultant acceleration of RID2- $\alpha$  in 15 km/h, 5.5g sled test.**

## ACCIDENT RECONSTRUCTIONS

As part of the European whiplash project a task was scheduled to reconstruct experimentally a number of real accidents in which car occupant had suffered minor neck injuries. One aim of these reconstructions was to investigate the possible link between dummy loading parameters and the occurrence of neck injuries since the main assumption in the European whiplash project was

that the risk on neck injuries would decrease with a lower neck loads.

Reconstructions have been conducted both in the first stage of the project with the RID 1 dummy and in a later stage with the RID2- $\alpha$  dummy. The dummies were used to represent the driver. In some of these tests the Hybrid III dummy was used to simulate a passenger. One general conclusion from the reconstructions was that the actual deformations occurring in the real accident were difficult to reproduce exactly. In this paper some of the results for the reconstructions with the RID2 dummy will be presented. In total five well-documented accident cases with AIS 1 injuries have been reconstructed with this dummy.

Table 2 presents the range of upper neck loads measured in the RID2- $\alpha$  dummy in the five reconstructions. Shear and axial forces are presented as well as neck torques. In this table also the results for neck loads presented in literature for different types of human subject tests are included. These tests were conducted at varying impact levels and with different restraint and seat types. Note that in most of these tests no injuries were reported (one of the PMHS subjects tested by Kallieris *et al.* had AIS 3 neck injury, caused by osteoporosis).

From the table it can be seen that the normal force is the only dummy loading parameter in the accident reconstructions, which deviates in value from the values found in the non-injury human subject tests. This parameter reaches a value up to 1650 N while in the non-injury human subject tests this value did not exceed a level of 504N. So this parameter possibly could be linked to the risk of low severity neck injuries, knowing that the neck loads measured in the RID2- $\alpha$  correlated well to the results of the human testing done in this project.

**Table 2. Loads in the upper neck adopted from several studies together with results from the accident reconstructions with the RID2- $\alpha$  ( last row) conducted in the European whiplash project.**

	Shear force [N]	Normal force [N]	Torque [Nm]	Seat	Subject	Injury	Amount of tests
Ono & Kanno (1993)	41-80	44-68	4.0-4.7	Rigid	Volunteer	No	5
Mertz & Patrick (1967)	218-441	125-504	16.8-44.8	Rigid	Volunteer	No	5
Kallieris (1996)	345-360	446-473	35.6-38.8	Rigid	PMHS	No	2
Deng (2000)	53-335	33-258	-2 - 39.5	Soft	PMHS	No	4
Yoganandan (2000)	257-525	369-904	22-46.6	Rigid	PMHS	AIS 2-3	5 (4 injury)
Kroonenberg (1997)	23-246	216-431	7-22	Soft	Volunteer	No	7
Bertholon (2000)	218-319	125-168	20-31	Rigid	PMHS	No	6
RID2- $\alpha$ (Whiplash)	77-328	584-1650	3.3-10.9	Soft	Dummy	AIS 1	5 reconstructions

## TEST METHODS

The following test methods were developed within this project: full system dynamical sled tests at three different impact speeds, geometrical tests and three tests to evaluate specific aspects of the seat/headrest performance dynamic seat back foam stiffness impactor testing at one impact speed (16 km/h) with a Hybrid III torso back form:

- dynamic head restraint foam and joint stiffness testing at one speed.
- quasi-static seat back load deflection testing at two velocities (10 and 16 km/h) for measuring combined recliner and foam stiffness with a Hybrid III dummy.

In this paper we will focus on the sled test method, since it is most relevant for the evaluation of seat and head restraint performance.

### Sled testing

Within the European whiplash project two accident databases have been investigated in detail to derive representative conditions for which whiplash injuries occur. Results of these studies as well as reconstruction data available were reviewed in order to define a suitable sled test configuration. Sled tests are recommended for seat and head restraint evaluation, since the same car seat design often is applied in several car types and for economical reasons (higher costs of full-scale testing).

**Impact conditions:** Both accident databases (GDV and VW) resulted in a similar rear impact configuration regarding the angle of the collision and overlap.

- Collision angle: straight (+/- 5°)
- Overlap: full overlap

This means that a relatively simple linear sled can be used.

**Velocity change of sled:** Three different sled velocities were selected:

- Low speed, 10 km/h (2.4g mean g-level): most common  $\Delta V$  at which whiplash occurs;
- Mid speed, 16 km/h (3.7g):  $\Delta V$  with a high injury risk.
- High Speed, 30 km/h (8.5g): This speed is less relevant for injury assessment but is needed to check the integrity of the system at higher speeds.

The crash pulse for sled testing was based on crash recorder data in both real accidents and accident reconstructions. The crash pulses are shown in Figure . The average pulse was calculated and idealised by two pulses, one with a trapezoid

shape and one with a sine shape. The advantage of these shapes is that they can be reproduced by most crash facilities quite easily.

**Seat mounting and adjustment:** The seat should be mounted on the sled in a configuration as much as possible corresponding to the mid-position mounting in the car. Additionally, the footboard and the position of the seatbelt anchorages must be similar to the configuration in the car. For the seat back inclination 25° torso inclination (design position) is proposed. Concerning the head restraint two positions, the optimum as well as the worst case are proposed to be analysed. .

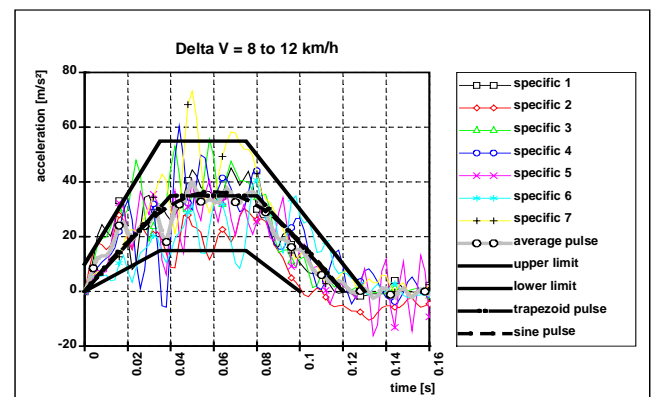


Figure 10. Crash Corridor at 10 km/h.

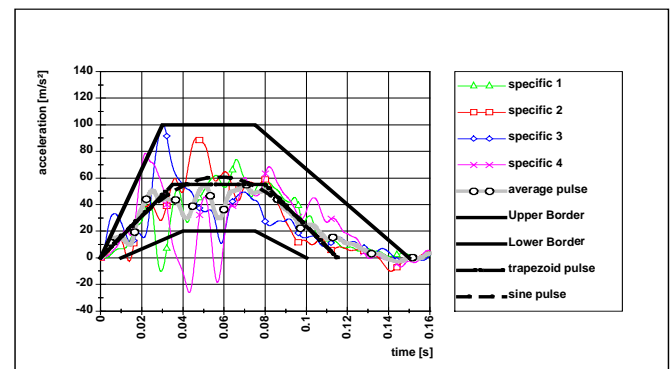


Figure 11. Crash Corridor at 15 km/h.

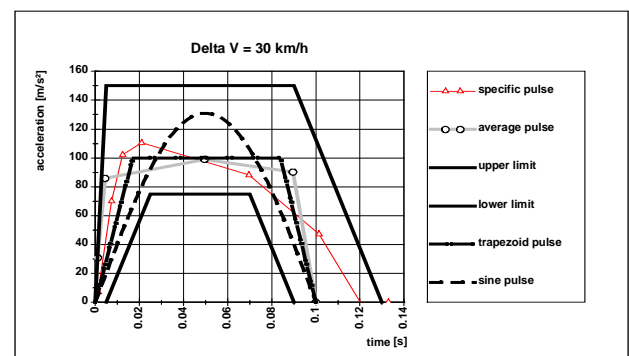


Figure 12. Crash Corridor at 30 km/h.

Dummy positioning requirements are:

- Pelvis angle:  $25^\circ \pm 2.5^\circ$
- H-point dummy with respect to H-point of seat:  $0 \pm 20$  [mm]
- head angle:  $0^\circ$

## BENCHMARKING

As part of the European whiplash project a limited benchmarking study was performed in order to evaluate the proposed test methods and in order to get a first impression of the performance of some of the seat/headrestraint system designs currently available in the European market.

### Test Seat Selection

Three front seats from European car manufactures were chosen for analysis in the benchmarking task. These seats are identified as WTS (Whiplash Test Seat) 1, 2 and 3, respectively. The test seats were chosen primarily because of their vast availability on the European Community market. Furthermore the selection was based upon the design features included in the seat. Criteria considered for the selection of the test seats included seat back recliner type, seat back foam type, head restraint design and usage of a seat height adjuster in the seat configuration. A summary of these design characteristics and the annual vehicle sales volume for the selected seat are presented in Table 3. The baseline reference seat, which was used in various phases of the Whiplash project, is included for reference.

## Benchmark Tests

The selected seats were tested according to the methods developed in the Whiplash program i.e. dimensional tests, the load-deflection quasi-static tests, and the dynamic sled tests at velocity changes of 10 km/h, 16 km/h, and 30 km/h. The results of the above mentioned tests were compared to those performed with the baseline reference seat.

Quasi-static tests: In the quasi-static tests a Hybrid III dummy is pressed into the seatback with an energy equivalent to a 10 km/hr dynamic test. Figure 13 shows the energy absorbed in the incliner versus the dummy displacement and Figure 14 the seatback foam deflection as function of compression force. WTS 1 and WTS 3 show a much lower incliner stiffness than the other seats and WTS 1 moreover has a much lower seat back foam stiffness

Full System Sled Tests: The RID2- $\alpha$  was used during the test series of 10 km/h and 16 km/h, while the Hybrid III dummy with a TRID neck was used in the 30 km/h tests in order to minimise the risk of damaging the RID2- $\alpha$  prototype manikin. The head restraint was put in the assumed worst case condition namely full down and full rear. The performance of the test seats was evaluated based on several parameters: upper neck loads (shear force, normal force and torque) and the NIC injury criterium (Boström, 1996). The maximum values of  $F_x$ ,  $F_z$ , and  $M_y$  in the 10 km/h and 16 km/h tests and the NIC values are shown in Table 4 and 5 respectively. For the 30 km/hr tests no results are included in these tables since both the WTS 1 and WTS 3 seat suffered significant structural failure in these higher velocity tests.

**Table 3.**  
**Overview of selected seats, corresponding vehicle sales volumes and design characteristics**

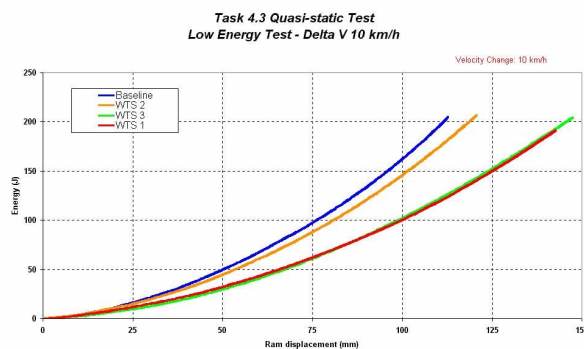
Test Seat	Annual Volume	Recliner Configuration	Seat Back Foam	Head Restraint	Height Adjuster
Baseline Reference Seat	480,000	Dual Side Continuous	Expanded Polyurethane	4 way movement / PU foam	No
WTS 1	200,000	Dual Side Continuous	Expanded Polyurethane	2 way movement / PU foam	No
WTS 2	175,000	Dual Side Discontinuous	Rubberised Coconut Hair	4 way movement / PU foam	Yes
WTS 3	420,000	Dual Side Continuous	Expanded Polyurethane	2 way movement / PU foam	No

**Table 4.**  
**Summary of peak upper neck loads and the NIC**  
**in  $\Delta V$  10 km/h sled tests**

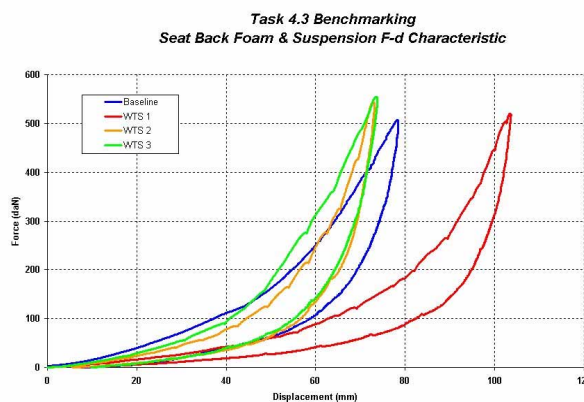
Test Seat	My	Fx	Fz	NIC
	Nm	N	N	m2/s2
WTS 1	-1.8	-88	870	9.9
WTS 2	-5	-185	1200	16.3
WTS 3	-7.8	-220	1017	15.7
Baseline	-7.6	-127	697	21

**Table 5.**  
**Summary of peak upper neck loads and the NIC**  
**in  $\Delta V$  16 km/h sled tests**

Test Seat	My	Fx	Fz	NIC
	Nm	N	N	m <sup>2</sup> /s <sup>2</sup>
WTS 1	-11.5	-68	872	20.6
WTS 2	-6.9	-470	2207	33.6
WTS 3	-22.8	-102	956	15.9
Baseline	-8.9	-175	1970	21



**Figure 13. Seat back incliner energy-displacement characteristics.**



**Figure 14. Seat back foam and incliner force-deflection characteristics.**

In the low severity 10 km/h tests the lowest loads and NIC values, are achieved in the tests with WTS 1. This seat has the lowest incliner and seatback foam stiffness. For the 16 km/h tests the differences are less pronounced. The WTS 2 seat clearly exhibits the largest neck forces but the neck torque is lower for this seat. The axial force is relatively large for all seats tested and concerning WTS 1 and 3 there is hardly a difference in this force if the impact severity increases. In all cases this force is from the same order of magnitude as in the accident reconstructions.

## DISCUSSIONS AND CONCLUSIONS

The European whiplash started in 1997. The most important result of this project is a sled test method and new crash dummy (RID2- $\alpha$ ) for the assessment of the protection offered by the seat and headrest system in a rear-end collision. On the basis of human subject tests conducted in the project, the development of a new rear impact dummy, the RID2- $\alpha$  was realised. Compared to the Hybrid III dummy a much more realistic biofidelity was observed for this dummy with respect to the human subject tests conducted in this project. It is recommended to evaluate the response of this dummy also to some other test series with human subjects that have become available recently. In addition to the biofidelity also the repeatability of the dummy has been evaluated and a satisfying performance could be observed. Some minor problems with the dummy have been identified which has resulted in some small design modifications (included in the 2001 update of the dummy).

Mainly for economical reasons the test method developed in this project is a sled test rather than a full scale test. Three different impact severity's are proposed: 10, 15 and 30 km/hr with a standard average crash pulse for each impact velocity. This crash pulse is derived from crash recorder data obtained from real and reconstructed accidents. It should be noted that the period of observation of the accident databases is 1975-1996, therefore it is recommended to consider crash pulses of new cars as well in order to check the validity of the average sled test pulses presented here. A disadvantage of an average pulse for a selected impact velocity is that specific vehicle response (crumple zones) is not taken into account. As an alternative it could be considered to prescribe a vehicle dependent acceleration pulse for the sled test.

The main assumption in this project was that whiplash risk may be related to neck loading. For this purpose a number of reconstructions of real accidents were conducted in which AIS 1 neck injuries were observed. Upper neck loads measured

in the dummy during the reconstructions have been compared with upper neck loads calculated in human subject tests. The limited data available so far indicate that only for the neck axial force such a relation with neck injury risk seems to exist. It should be noted that axial force can be compressive, during ramping up and when the head hits the head restraint, or tensile, during large head extension. Both forces may result in different injury mechanisms. Further research is needed to explore these mechanisms and also other potential criteria like lower neck loads should be considered.

With the newly developed dummy and the proposed seat and head restraint test methods, several existing car seats available on the European market were evaluated. It was found that seats with a low stiffness for the seat back incliner and seat back foam produced the lowest values of upper neck loads. All seats tested showed relatively large axial neck loads from the same order of magnitude as observed in the accident reconstructions. The largest axial neck loads were observed in the seat with the largest incliner and seatback foam stiffness. It should be noted that in all these tests the headrests was positioned in the assumed worst case condition (i.e. low and as far as possible backward).

In the European whiplash project so far only the extension phase of a rear-end collision has been considered and not the rebound phase in which due to the elasticity of the seat/headrestraint system the human body is pushed forward in a later stage of the collision. Several studies have indicated the potential risk of this rebound phase. In a follow-up project of the European whiplash project (called WHIPLASH II) the neck injury risk in the rebound phase will be studied together with the risk in frontal impacts.

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## REFERENCES

Bertholon, N. Robin, S., Le-Coz, J-Y., Potier, P., Lassau, J-P., Skalli, W. *Human head and cervical spine behaviour during low-speed rear-end impacts: PMHS sled tests with a rigid seat.* In: Proceedings IRCOBI Conference 2000.

Boström, O., Svensson, M.Y., Aldman, B., Hansson, H.A., Håland, Y., Lövsund, P., Seeman, T., Suneson, A., Säljö, A., Örtengren T. *A new neck injury criterion candidate based on injury findings in the cervical spinal ganglia after experimental neck extension trauma.* In Proceedings IRCOBI Conference 1996. pp123-136.

Cappon, H.J., Philippens, M.M.G.M., Van Ratingen, M.R., Wismans, J.S.W.M. *Evaluation of dummy behaviour during low severity rear impact.* In: Proceedings IRCOBI Conference 2000.

Davidsson, J., Svensson, M.Y., Flogård, A., Håland, Y., Jakobsson, L., Linder A., Lövsund, P., Wiklund K. *BioRID I – A New Biofidelic Rear Impact Dummy.* In: Proceedings IRCOBI Conference 1998 (a). pp 377-390

Davidsson, J., Deutscher, C., Hell, W., Linder, A., Lövsund, P., Svensson, M.Y. *Human Volunteer Kinematics in Rear-End Sled Collisions.* In: Proceedings IRCOBI Conference 1998 (b). pp 289-302

Davidsson, J., Flogård, A., Lövsund, P., Svensson, M. *BioRID P3- Design and Performance compared to Hybrid III and Volunteers in Rear Impacts at  $\Delta V=7$  km/h.* In: Proceedings 43<sup>rd</sup> Stapp Car Crash Conference 1999 (a). pp 253-265

Davidsson, J., Lövsund, P., Ono, K., Svensson, M.Y., Inami, S. *A Comparison between Volunteer, BioRID P3 and Hybrid III performance in Rear Impacts.* In: Proceedings IRCOBI Conference 1999 (b). pp 165-178

Deng, B., Begeman, P.C., Yang K.H., Tashman, S., King A.I.: *Kinematics of Human Cadaver Cervical Spine During Low Speed Rear-End Impacts.* In: STAPP Car Crash Journal 44, 2000, pp 171-188

Hell, W.; Langwieder, K., Walz, F. *Reported soft tissue neck injuries after rear-end car collisions.* In: Proceedings IRCOBI Conference 1998. pp 261-274

Hell W., Schick S., Langwieder K., *Epidemiology Of Cervical Spine Injuries in Rear-End Car Accidents and Influence of Different Anthropometric Parameters in Human Volunteer Testing.* In "Frontiers in Whiplash Trauma", Yoganandan, IOS Press, 2000.

Kallieris, D., Rizzetti, A., Mattern, R., Thunnissen, J., and Philippens, M.: *Cervical Human Spine Loads During Traumatomechanical Investigations.* In: IRCOBI Proceedings 1996. pp89-106

Kroonenberg, A van den., Philippens, M., Cappon, H., Wismans, J., Hell, W., Langwieder, K. *Human Head-Neck Response During Low-Speed Rear End Impacts*. Stapp Car Crash Conference Proceedings, 1998. SAE 983158

Mertz, H.J. and Patrick, L.M. (1967): *Investigation of the Kinematics and Kinetics of Whiplash*. In: Proceedings 11th STAPP Conf. SAE 670919

Mertz, H.J. and Patrick, L.M. (1971): *Strength and Response of the Human Neck*. In: Proceedings 14th STAPP Car Crash Conference. SAE 710855

Ono, K. and Kanno, M. (1993): *Influences of Physical Parameters on the Risk to Neck Injuries in Low Impact Speed Rear-end Collisions*. In: Proceedings IRCOBI pp 201-212.

Ono, K., Kaneoka, K., Wittek, A., Kajzer, J.: *Cervical Injury Mechanisms Based on the Analysis of Human Cervical Vertebral Motion and Head-Neck-Torso Kinematics during Low Speed Rear Impacts*. In: Proceedings 41<sup>st</sup> STAPP Car Crash Conference, SAE 973340, 1997

Prasad, P., Kim, A., Weerappuli, D.P.V. *Biofidelity of Anthropomorphic Test Devices for Rear Impact*. In: Proceedings 41<sup>st</sup> STAPP Car Crash Conference 1997. pp 387- 415, SAE paper 973342.

Scott, M.W., McConnell W.E., Guzman, H.M., Howard, R.P., Bomar, J.B., Smith, H.L., Benedict, J.M., Raddin, J.H., Hatsell, C.P. *Comparison of Human and ATD Head Kinematics During Low-Speed Rear-end Impacts*. In: Proceedings 37<sup>th</sup> STAPP Car Crash Conference 1993. pp 1 – 8. SAE paper 930094.

Temming J., Zobel R. *Frequency and risk of cervical spine distortion injuries in passenger car accidents: Significance of human factors data*. In: Proceedings IRCOBI Conference 1998. pp 219-234

Temming, J., Zobel, R. *Neck distortion injuries in road traffic crashes (Analyses of the Volkswagen database)*. In: "Frontiers in Whiplash Trauma", Yoganandan, IOS Press, 2000. pp 118-133

Thunnissen, J., Ratingen, M. van, Beusenberg, M., Janssen, E. *A dummy Neck for Low Severity Rear Impacts*. ESV Conference 1996. Paper 96-S10-O-12.

Yoganandan, N., Pintar, F.A., Stemper, B.D., Schlick, M.B., Philippens, M., Wismans, J.: *Biomechanics of Human Occupants in Simulated Rear Crashes: Documentation of Neck Injuries and Comparison of Injury Criteria*. In: STAPP Car Crash Journal 44, pp 189-204, 2000.